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ACD³ - a new framework for activity-centered design

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Abstract

During the design process of a product, a variety of design variables are gradually determined – this happens either intentionally when design decisions are made, or unintentionally when design variables are determined by limitations brought about by circumstances. At the same time, product development in teams complicates the design process if the interdependencies of design decisions are not transparent. If decisions are made at the wrong time, or not at all, the design may not end up being coherent with the product's overall purpose, which negatively impacts the final result of the development. To address this problem, the present paper presents the ACD³-framework, a newly developed product development mapping tool that visualizes where design decisions can be coherently made through a clear structure, while allowing flexibility so as not to inhibit a design organization's innovation and creativity. To map the interrelationship between several design aspects at once, the framework is made up of three dimensions of design (the D³ in ACD³): levels, perspectives and activities. The three dimensions provide a systemic and systematic framework that organises design work at different abstraction levels within a common structure. From this foundation, two coherent models that together make up the framework are derived: the *ACD³-matrix* and the *ACD³-process*. These models are useful for planning and carrying out the right activities, at the right level in the organization, at the right stage of the development work.

Keywords: Activity-centered design, product development, systematic design process

1 Introduction

Product development is an activity that is inherently creative, fuzzy, unpredictable, exploring, bilateral, researching and iterative. Moreover, the process is often carried out by teams of multiple actors with different areas of functional expertise and responsibility, further complexifying the process of actively making design decisions that take into account the many goals and targets the product must meet. Therefore, prescriptive approaches for how to carry out a complex product design process are essential to guide and support the work of such teams.

A common issue in product development regards communication within and beyond the project. For example, Tortorella, Marodin, De Castro Fettermann, & Fogliatto (2016) identify thirteen main problems for Lean Product Development, two of which are "Achieve true cross-functional integration" and "Lack of communication and feedback", while Lehtinen, Virtanen, Heikkilä, & Itkonen (2015) state that insufficient collaboration between product owner and the development team is one of four main problems in Scrum projects. Furthermore, Beverland, Micheli, & Farrelly (2016) emphasize the need for cooperation between marketing and design in product development. A third issue is that process and project management frameworks sometimes are too rigid and linear to support innovation, indicating that more flexible approaches are needed (Felekoglu, Maier, & Moultrie, 2013; Jetter & Albar, 2015).

In projects it can be beneficial to organise the design work in multiple dimensions, e.g. to emphasise both phases and activities, or to emphasise both linear and iterative flows in the process. Generic models for a systematic design process exist, some of which are well-known and widespread (e.g. Dubberly, 2005; ISO, 2010; Pahl, Beitz, & Wallace, 1996; Ullman, 2010; Ulrich & Eppinger, 2011). However, most of these models describe the design process in one dimension, with one type of perspective or feature making up the backbone of the process. Often, the processes are dived into phases or activities originating from one type of main flow, implying either a linear/ sequential hand-off of design responsibility from one stakeholder to the next, or an iterative/cyclic involvement of all functional roles in the organization.

Since design projects are often unique and the configuration of team members and specializations varies across organizations, the process frequently needs to be customised. The main issue with not having an adequate process framework is that it is difficult for a team to find guidance regarding which decisions to make, which activities to do, when to do them, and with whom. This can result in miscommunication, sub-optimisation, missed opportunities and/or higher costs. This points toward a need to combine models into a general adaptable framework for multi-dimensional design processes, that specifically visualises the decisions and activities.

To address the needs described above, this paper presents the product development framework *ACD³*, a newly developed coherent framework with the purpose to reveal where design decisions are made in relation to phases and activities in product development. The framework visualises a clear structure for where certain design decision types belong, but allows flexibility so as not to inhibit the product development organization’s innovation and creativity. The ACD³ framework is intended for use in product development projects to manage decisions and activities that should be addressed among the different actors in the process. The ACD³ framework presents three independent design process dimensions: *design levels*, *design perspective* and *design activities*. From this foundation, two coherent models that make up the framework are derived: 1) the *ACD³-matrix*, which visualises the precedence relationship between design decisions in the design process, and 2) the *ACD³-process*, which describes the design process in terms of both a linear workflow (phases) and an iterative work flow (repeated activities). This paper begins with describing the theoretical foundation for the ACD³ framework, followed by a walkthrough of the three dimensions. After that, the matrix and the process are presented. The paper ends with a summarising discussion of the ACD³ framework.

2 Origin of the ACD³ framework

The ACD³ framework originates from the authors' experiences from industrial product development projects and teaching in industry and academia. The framework has a theoretical basis in systems theory (particularly activity theory (Karlsson, 1996) and systems engineering (INCOSE, 2016), product development, and human factors (IEA, 2016)). ACD³ emerged as a result of combining different frameworks and process models in these areas into a coherent whole, with the aim of enabling a clearer understanding of a design process, as in making it easier to implement and teach. In order to accomplish this, the cornerstones of ACD³ – a number of basic assumptions elicited from a theoretical basis (Bligård, 2015) – frame and provide key elements of the design process. Before describing the cornerstones of the ACD³, a clarification is needed; the ACD³ framework uses the term "machine" to describe the artefact that the end users will be interacting with, i.e. the product being developed. The term was chosen to embrace both simple products and complex technical systems, and to emphasise the human-technology interaction aspect.

The first cornerstone of the ACD³ framework is that the *utility* of a machine emerges only when it is used. A machine cannot have built-in utility; rather, the utility is the result of when the machine is used within a system to achieve the relevant objectives. A consequence of this reasoning is that the focus of the design process is to achieve a *successful interaction between human and machine*, i.e. the process is *activity-centered*, a.k.a. *Use-Centred Design*. What distinguishes Use-Centred Design from the more classical *User*-Centred Design is that the former focuses on the objectives and tasks that are carried out within the specific domain where the problems are (Bennett & Flach, 2011). In User-Centered Design, the focus is instead on the needs, desires and limitations of the end user. The match between human, activity and environment is therefore more central to Use-Centred Design, aiming towards a successful design of the machine (which in turn is defined as achieving the intended purpose). Hence, one central tenet of the ACD³ framework is to *first design the use,* and that the use in turn determines the design of the machine.

The second cornerstone is the concept of *design variables*. A design variable is a property related to the machine that can be specified from the point of view of the designer, which implies that there are numerous design variables in a development project that may be determined consciously if and when a *design decision* is made. Design variables include physical aspects like colour and shape, as well as more abstract aspects like functions and work sequences. A design variable consists of two parts. The first is the property (e.g. the length of a car) and the second is the value (e.g. 5 meters). In a design, variables are often interdependent, e.g. a machine's weight may depend on how much internal battery capacity it requires. A design decision is made when the possible value of a design variable is constrained, i.e. a design decision eliminates other variants once the choice is made. It is important to realize that a design variable is *always* determined in a design process, regardless of whether this is due to an active decision or if it results unintentionally. In the latter case, the content of the design variable will be a consequence of other design constraints that are made, both intentional and unintentional; their interdependence results from the precedence relationship between the variables.

Even though many process models emphasise the iterative nature of design, the ACD³ framework assumes a gradual emergence of the machine in the process. The design of the machine is carried out in phases, where the chosen solution gradually becomes more precise and detailed for each subsequent phase (and the iterations exist mainly within the phase). in In the same manner as the gradual emergence of the design, Requirements are mainly used to narrow down the design space, and it is assumed that the requirements emerge gradually and become more detailed and precise as the process progresses. ACD³ emphasises that design is ideally a top-down activity, where the big picture informs the details. This view fits with many project management philosophies that emphasise “tollgates” between phases.

A related assumption is that during the design process, a machine can and should be viewed from shifting systems perspectives. In some cases, process models found in literature have individual steps for e.g. problem analysis, function allocation, task analysis, concept development etc. ACD³, by contrast, stresses that shifting system perspectives is relevant to all sequential phases in a design process, since this highlights different aspects of the design at different systems levels.

3 The three dimensions of ACD³

To map the interrelationship between several design aspects at once, the framework is made up of three dimensions of design (the D^3 in ACD^3): *levels*, *perspectives* and *activities*. The *levels* dimension describes the degree of precision and specification of the solution. The *perspectives* dimension describes the different ways of viewing the solution, i.e. different aspects in focus. The *activities* dimension describes the work that is done to identify the design variables, make the design decisions and communicate them.

3.1 Design levels

Design levels (derived from abstraction levels) describe the machine with shifting degrees of precision and specification. For each level, the precision of detail is gradually increasing while the design space is gradually decreasing. ACD^3 includes five design levels, which are based on different and distinct system views (Table 1.)

Table 1. Design levels, exemplified with a vacuum cleaner

Design level	System view	Description	Example: vacuum cleaner
Effect	Socio-technical system	The effect that the machine is intended to achieve the context	A cleaner home
Usage	Human-machine system	The use of the machine by humans	Manually moving the device when cleaning
Architecture	Machine system	The technical architecture of the machine	An electrical motor that sucks air through a filter
Interaction	Machine interfaces	The interaction between human/context and machine in details	Design of the physical form and user interface
Elements	Sub system	The technical elements of the machine	Structural design of the motor, the dust bag etc

The first top-down design level is the *effect* (also known as the *intended purpose* of the machine), i.e. the impact that humans want to achieve with the help of the machine. The effect is manifested in the socio-technical system, and can affect both humans and the environment. The second design level is the actual *usage* and how it is performed to achieve the desired effects. The intended use is a means for the machine to achieve the effect. The third design level is the *architecture* of the machine. It is the technical functionality and the technical structure that together will enable the use. The fourth design level is the *interaction*, or how the machine's architecture should respond to and interact with humans and the environment in order to achieve the intended purpose. The fifth design level is *elements*, i.e. the machine's technical *subsystems*, and they describe how the machine is designed in detail to fulfil partial tasks that have been decided in the overarching design levels.

When the five design levels are applied in a design process, they can be used for two purposes. The first is to indicate an appropriate sequence of steps to develop the machine during the development work, which is useful for organising the activities. The second is to function as a template for describing the design of the machine at different levels of abstraction, which is useful for documentation.

3.2 Design perspectives

The design perspectives highlight that the same solution can be described in different ways and emphasize different aspects. The design perspective is a conceptual tool for organising the design variables. ACD³ contains five design perspectives, i.e. five main types of design variables to determine; *Problem, Structure, Function, Activity and Realisation* (Table 2). The design perspectives are present throughout the whole design process and they are found in each of the five design levels. Within the workflow iterations, the design is updated through the perspectives and becomes more detailed and precise as the design process progresses.

Table 2. Design perspectives exemplified with a vacuum cleaner

Perspective	Description	Examples vacuum cleaner (range of examples at different design levels)
Problem	What issues are in focus and drive the process forward?	Effect level: What type of cleanliness do people want? Elements level: How to achieve structural integrity of the motor?
Structure	What entities are included in the system and how they are related?	Effect level: Who are the stakeholders? Elements level: What are the components in the electronics?
Function	What abilities must the system have to reach the goals??	Effect level: How and what to clean? Elements level: What functionality for the components?
Activity	What do the actors need to do in the system?	Effect level: What is the intended use? Elements level: What are the machine processes?
Realisation	How is the system concretised?	Effect level: What are possibilities and limitations? Elements level: How is the design of the components?

3.3 Design activities

The design activities describe the work that is done in the sequential design process to identify, determine and communicate the design variables, which together form the solution. ACD³ specifies seven design activities:

- *Planning* - continuous planning of the activities to be performed
- *Data collection* - collection of information necessary for the development
- *Analysis* - clarifying which factors influence the issues to be solved in the upcoming solution and the possible content in the design space
- *Ideation* - generating suggestions for how the issues should be addressed
- *Synthesis* - creating the solutions, making design decisions and formulating requirements
- *Evaluation* - evaluating the solutions developed to determine if they are acceptable
- *Documentation* - continuous documentation of the activities and what they result in

The design activities are iterated throughout the development process. They span across both the design levels and the design perspectives, thus capturing the iterative nature of the design process.

3.4 Summary of Dimensions

Combining the three dimensions provides a systematic and systemic framework that unites design work with a coherent structure. Each dimension has a clear focus related to design that can be incrementally described across a continuum, but does not predetermine a particular state for the other dimensions. For example, in the design level *architecture*, all design perspectives and design activities are relevant. Consequently, the dimensions can combined to create useful tools to support decision-making regarding design variables and design work (particularly in cross-functional teams) within the development project. This is done by combining them in two ways to form the ACD³-matrix and the ACD³-process (Figure 1). They are described in detail in the following sections.

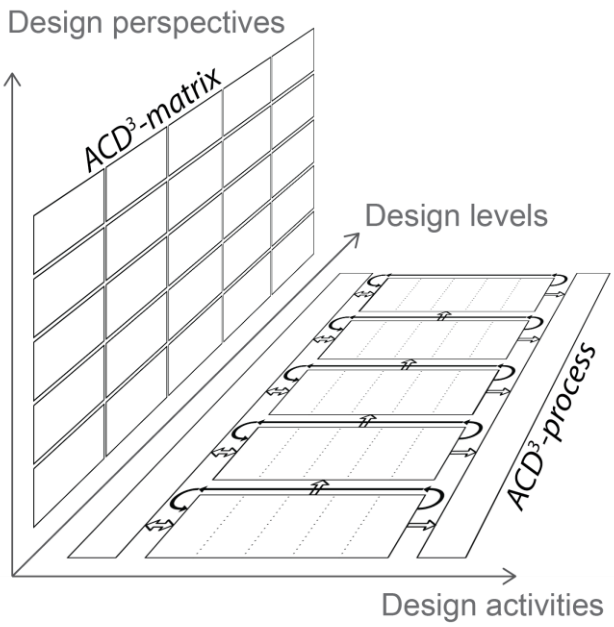

Figure 1. The ACD³-matrix and the ACD³-process within the three dimensions of ACD³

4 The matrix and the process

4.1 ACD³-matrix

The ACD³-matrix combines the design levels and the design perspectives (Figure 2) in order to visualise the relationship between design decisions. Each cell in the matrix contains one or more types of design variables that need to be specified and determined, i.e. the *result* in the design process.

Within the matrix, a horizontal and vertical relationship between the cells becomes evident. Within each design level (vertical axis), the design perspective is a consequence of the perspectives in cells above, and affects (constrains) the perspectives that are underneath; e.g., the system functions depend on the human-machine systems and then affect the user tasks. Horizontally, each design perspective becomes more and more specified for each design level moving from left to right; e.g., overall interaction is more specified than the user task, which in turn is more specified than the intended use.

Design perspectives \ Design levels	Effect	Usage	Architecture	Interaction	Elements
Problem	Main problem	Usage problem	Architecture problem	Interaction problem	Element problems
Structur	Users, stakeholders and context	Human-machine system	Logical architecture machine	Detailed subdivision machine	Logical architecture elements
Function	Capabilities and values	System functions	Machine functions	Control and information	Element functions
Activitity	Intended use	User tasks	Overall interaction	Detailed interaction	Machine process
Realisation	Possibilites and limitations	Technical principle och introduction	Overall design	Physical form and interfaces	Implementation elements

Figure 2. The ACD³-matrix in detail, with type of design variables in each cell

The matrix clearly shows the design variables that need to be examined and determined during the development. While it is possible to view the framework as prescriptive, and to consider the design levels and design perspective as a logical sequence of work, in practice one level or perspective does not need to be completed before work begins on the next level or perspective (this is a conclusion from the authors' industrial experiences of iterative work). At some occasions in the design process, it may be advantageous to explore the next step in the sequence earlier, to get a more complete view of which design decisions will have the largest impact on the subsequent levels.

However, in order to achieve a coherent systematic development work (and thus avoid infinite loops), both the design levels and the design perspectives need to be finalised in descending order. The Effect is the first level that needs to be finalised, while the level of Elements is the last, and within the level the Problem perspective is the first that needs to be addressed, while Realisation is the last. Completing the design work in this order increases the chance that desired effects are achieved through a consistent harmonisation of the machine's functionality and execution, as a result of intentional design decisions. Reversing the order or working haphazardly without completing steps in sequence increases the risk of the design becoming the consequence of chance, or unintentional combinations of constraints, which may have unpredictable impacts on the overall goal for the machine.

Therefore, the main use of the ACD³-matrix is to act as a map that helps designers make the relevant design decisions in the proper order, i.e. clarify the governing conditions that need to be considered first and then focusing the synthesis. In this way, the ACD³-matrix systematically and systemically structures the design decisions.

4.2 ACD³-process

ACD³ contains an iterative design process, termed the ACD³-process. The ACD³-process combines the design levels and the design activities (Figure 3) in order to describe the design process in two workflows, making it both a linear and iterative model.

The process consists of five phases: *needfinding, design of use, overall design, detailed design, and component design*. This division stems from the design levels. Each phase contains seven design activities: planning, data collection, analysis, ideation, synthesis (including formulation of requirements), evaluation and documenting. The structure of the ACD³-process emphasises that planning and documenting are continuously ongoing throughout the development project in parallel with the design activities in the phases. The ACD³-process should be seen as several phases with all seven design activities being iterated within each phase.

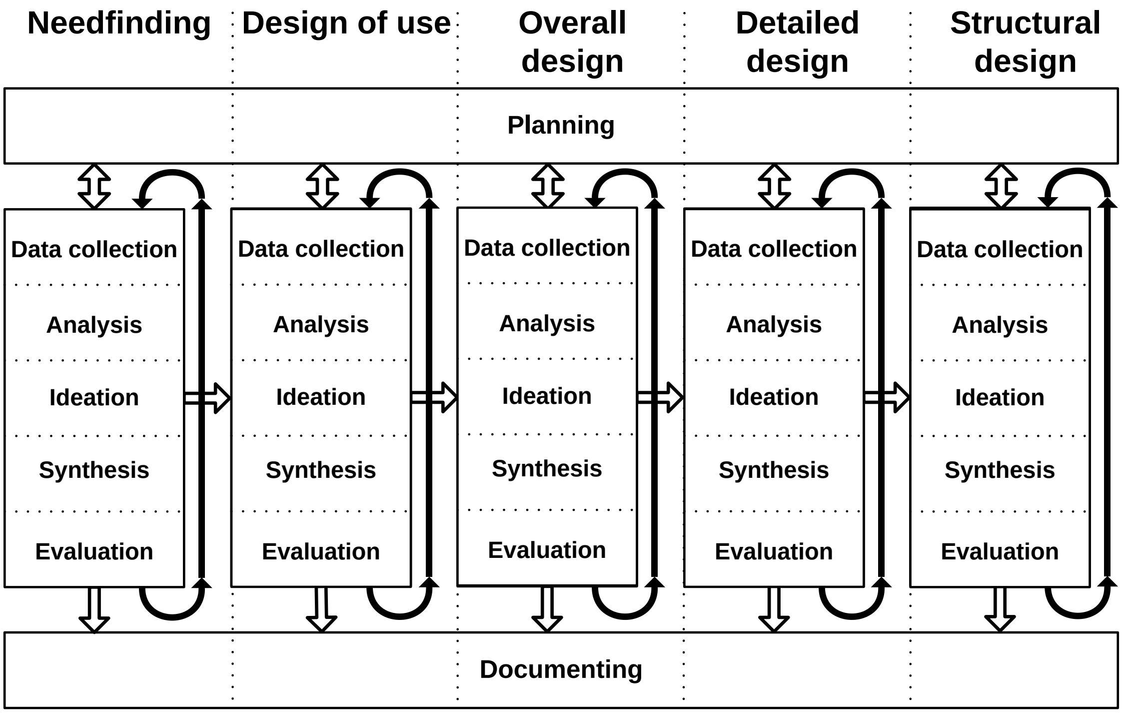

Figure 3. The ACD³-process in detail

The ACD³-process is useful for planning design activities in the right sequence at the right design level in a product-developing organization. It visualises a clear link between different design variables through the design levels and the organisation of the various types of design work needed. Thus, the ACD³-process systematically and systemically structures the design activities within a development project.

5 Summarising discussion

This paper has, theoretically and conceptually, presented the ACD³ framework, a mapping and visualisation framework to help product development teams perform coherent activity-centred design. ACD³ is a general framework that brings together the different dimensions in existing theoretical models of design processes, into a coherent exploration and gradual constraining of the design space. ACD³ specially emphasizes that design decisions, which are important for design engineers (Henriksson & Johansen, 2015), must be taken actively.

As stated earlier communication within and beyond product development projects remains an issue in product development (Tortorella et al., 2016). The ACD³ framework addresses some of these documented weaknesses, by visualising the design decisions and design activities at different stages of the design process, in a structure that is consistent in all phases of the product development. The structure of ACD³ enables an overview that makes it easier to see the interdependencies between design team members' responsibilities and makes the design work easier to plan, communicate and discuss. The ACD³-matrix offers stakeholders a platform for dialogue, to ensure that design decisions are well-coordinated and consistent with overall purposes and desired effects. Moreover, the matrix makes it easier to identify which level and perspective an issue is related to, which decreases the probability for misunderstandings and increases the chance that appropriate stakeholders are given mandate for specific design decision.

The process flexibility that can counteract the innovation-hampering rigidity and linearity of process and project management (Felekoglu et al., 2013; Jetter & Albar, 2015) is addressed in the ACD³-matrix by showing which design decisions that need to be taken, but without dictating in which order. This enables product innovation starting from a technical possibility and finding a possible use for it, so-called "technology push". For instance, it is possible to start from the right side of the matrix, examining the product dimensions from the perspective of technical solutions and working through the matrix to the left to establish a possible use that provides a desirable effect for the users. The ACD³-matrix acts as a map to ensure that all design variables are actively decided upon in the development work, rather than becoming a passive consequence of other choices. The ACD³-matrix allows an increasing focus on details by describing different types of design variables, but the specific variables have to be indentified within the project. This gives the ACD³ framework adaptability and flexibility.

In very recent literature, other product development frameworks have appeared that also aim for a multi-dimensional perspective on product development, but with different foci. For example, Vila & Albiñana (2015) present a framework focusing on new product development (NPD) and innovation, striving to manage knowledge resources when innovating products. Theirs is a general framework aimed at managers of product development processes with a life-cycle perspective, but compared ACD³ the framework has less comprehensive resolutions of the early phases of NPD (e.g. no design of effect and use) and less emphasis on the different types design decisions.

From a Technology Forecasting perspective, Becattini, Cascini, & Nikulin (2015) propose a modelling framework that also helps facilitate a decision-making process with a visualization of a product or process requirements; the difference from ACD³ lies in the fact that it is not meant to serve as a mapping tool for entire teams, and the design decision instances are implicit, rather than explicit, in the model. Schuh, Sommer, & Rudolf (2015) propose a framework that focuses on developing a product architecture and aligning it with organizational and processual [sic] implementation, but this rests on a pre-condition that product architecture is based on mutually independent modules; in contrast, ACD³ has a focus on complex products with strong interdependencies between design decisions, i.e. a development philosophy that is holistic and intertwined rather than modular. Song, Cao, & Zheng (2016) present a framework that guides the product innovation process in four steps, but it remains high-level and does not guide the design decisions at the detailed technical solution level.

The next step in the development of ACD³ is to empirically evaluate the framework. Two activities are planned: a focus group study with companies that work with NPD and testing the framework with master thesis workers in NPD. Later on, the goal is to test the ACD³-framework in a real company case to study how ACD³ will affect teamwork and design decisions.

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